Hybrid Rice Breeding & Seed Production

FANGMING XIE

International Rice Research Institute
DAPO BOX 7777
Metro Manila, Philippines
f.xie@cgiar.org
What is Hybrid Rice?

The first generation offspring of a rice cross between two genetically diverse parents
How Hybrid Rice?

**Normal Rice Spikelet**
(self pollinated crop)

**Sterile Rice Spikelet**
(Male Sterility)

**Hybrid Seed Production**
(Male Sterile x Normal Rice)
Why Hybrid Rice?

- **Heterosis (Hybrid vigor) Application to Increase:**
  - Productivity (yield/unit/time, 15-20% of yield advantage), and
  - Economic returns

- **Heterosis**
  - A universal phenomenon that F1 generation shows superiority to both parents in agronomic traits or yield
  - It presents in all biological systems and has been exploited commercially in many agricultural crops.
How to Measure heterosis?

**Mid-Parent (MP) heterosis**
(F1 performs better than mean of two parents):
\[
\frac{F1}{MP} \times 100
\]

**Better Parent (BP) heterosis**
(F1 performs better than better parent):
\[
\frac{F1}{BP} \times 100
\]

**Standard heterosis***
(F1 performs better than the check variety):
\[
\frac{F1}{CK} \times 100
\]

*Standard heterosis is the most useful term in commercial crop production*
Male Sterility Systems in Rice

- Male sterility: a condition in which the pollen grain is unviable or cannot germinate and fertilize normally to set seeds.

- Male Sterility Systems (genetic and non-genetic):
  - Cytoplasmic genetic male sterility (CMS)
    Male sterility is controlled by the interaction of a genetic factor (S) present in the cytoplasm and nuclear gene (s).
  - Environment-sensitive genic male sterility (EGMS)
    Male sterility system is controlled by nuclear gene expression, which is influenced by environmental factors such as temperature (TGMS), daylength (PGMS), or both (TPGMS).
  - Chemically induced male sterility
    Male sterility is induced by some chemicals (gametocides)
Brief history of hybrid rice

✓ 1926 - Heterosis in rice reported
✓ 1964 - China started hybrid rice research
✓ 1970 - China discovered a commercially usable genetic tool for hybrid rice (male sterility in a wild rice = **Wide Abortive**)
✓ 1973 - **PTGMS** rice was found in China
✓ 1974 - First commercial **three-line** rice hybrid released in China
✓ 1976 - Large scale hybrid rice commercialization began in China
✓ 1979 - **IRRI** revived research on hybrid rice
✓ 1981 - **PTGMS** rice genetics and application was confirmed
✓ 1982 - Yield superiority of rice hybrids in the tropics confirmed (**IRRI**)
✓ 1990s - India and Vietnam started hybrid rice programs with **IRRI**
✓ 1991 - More than 50% of China’s riceland planted to hybrids
✓ 1994 - First commercial **two-line** rice hybrid released in China
✓ 1994 - 1998 - Commercial rice hybrids released in India, Philippines Vietnam
Rice and Hybrid Rice Production in China

![Graph showing the area (million ha) of Total Rice Area, Hybrid Rice Area, and percentage of Hybrid rice area from 1976 to 2002. The graph indicates an increase in the area of Hybrid Rice and a corresponding decrease in the percentage of Hybrid rice area over the years.](image-url)
Rice Grain Yield in China

Grain yield (kg/ha)

Year

Hybrid rice
Inbred rice
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangladesh</td>
<td>15</td>
<td>50</td>
<td>90</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>India</td>
<td>100</td>
<td>200</td>
<td>560</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td></td>
<td>10</td>
<td></td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Myanmar</td>
<td>2</td>
<td>42</td>
<td></td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Philippines</td>
<td>13</td>
<td>189</td>
<td>367</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Vietnam</td>
<td>188</td>
<td>480</td>
<td>650</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>288</td>
<td>710</td>
<td>1,445</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Two Commercial Systems for Hybrid Rice

Three-Line Hybrid Rice Production

CMS Multiplication

A X B

A X B

A X B

Hybrid Seed Production

A X R

A X R

A X R

Hybrid Production

F1

F1

F1

Two-Line Hybrid Rice Production

S-line Multiplication

S

S

S

Hybrid Seed Production

S X R/P

S X R/P

S X R/P

Hybrid Production

F1

F1

F1
Requirements for 3 Lines in CMS System

- **A-line**
  - Stable Sterility
  - Well developed floral traits for outcrossing
  - Easily, wide-spectrum, & strongly to be restored

- **B-line**
  - Well developed floral traits with large pollen load
  - Good combining ability

- **R-line**
  - Strong restore ability
  - Good combining ability
  - Taller than A-line
  - Large pollen load, normal flowering traits and timing
TGMS and two-line hybrid

- Based on the discovery of P(T)GMS mutant
- Male sterility controlled by 1 or 2 pairs of recessive gene(s)

Model of Sterility / Fertility Expression for TGMS Rice
Source Nursery
- Elite lines from different sources
- To evaluate parents and make testcross

Testcross Nursery
- B & R line Breeding Program
- P line Breeding Program
- To identify B, R & P lines
- Backcross CMS pairs (BC1)
- Preliminary heterosis evaluation, 2 rows w/ parent

CMS Backcross Nursery
- BC2-BC4, CMS Evaluation

AxB Paircross
- Breeder Seeds

AxB Increase
- Core Seeds

AxB Seed Production
- Foundation Seeds

AxB Seed Production
- Certified Seeds

A & B Line Release

Retestcross Nursery (OYT)
- Hybrid Seed Production for OYT
- Isolation Bags or hand-crossing
- Re-evaluate F1 hybrids
- Stage 1, 1 rep, 3 rows

Preliminary Yield Trial (PYT)
- Hybrid Seed Production for PYT
- Isolated Net or bags
- Stage 2, 1 rep, plot

Advanced Yield Trial (AYT)
- Hybrid Seed Production for AYT & NYT
- Isolation Block
- Stage 3, 3 reps, plot

National Yield Trial
- Hybrid Pilot Seed Production
- Isolation Block
- Stage 4, 3-4 reps, multi-location, 2-years

On-Farm Trial (Strip Trial)

Hybrid and R Line Release

Flowchart of 3-Line Hybrid Rice Evaluation and Seed Production
Flowchart of 2-Line Hybrid Rice Evaluation and Seed Production

TGMS Line Breeding
- Breeder Seeds
  - Core Seeds
    - Foundation Seed
      - Certified Seeds
        - TGMS Line Release

SOURCE NURSERY
- Elite lines from different sources
- B & R line Breeding Program
- Pollinator line Breeding Program
  - To evaluate parents and make testcross
  - To identify TGMS & P lines
  - Hybrid Seed Production for OYT
    - Isolation Bags or hand-crossing

TESTCROSS NURSERY
- Core Seeds
  - Hybrid Seed Production for OYT
    - Isolation Bags or hand-crossing

RETESTCROSS NURSERY (OYT)
- Foundation Seed
  - Hybrid Seed Production for PYT
    - Isolated Net or bags
  - Preliminary Yield Trial (PYT)
    - Stage 1, 1 rep, 3 rows
    - Hybrid Seed Production for PYT
      - Isolation Block

On-Farm Trial (Strip Trial)

Advanced Yield Trial (AYT)
- Stage 3, 3 reps, plot

National Yield Trial
- Stage 4, 3-4 reps, multi-location, 2-years

Isolation Block

Hybrid Pilot Seed Production
- Isolation Block
- Hybrid and R line Release

National Yield Trial
Advantage & Disadvantage of 3-line hybrid rice system

- **Advantages**
  - Stable male sterility

- **Disadvantages**
  - Limit germplasm source (CMS, Restorer)
  - Dominant CMS cytoplasm in large area (WA)
  - One more step for parental seed production
  - Time consuming of CMS breeding
Advantage & Disadvantage of 2-line hybrid rice system

- **Advantages**
  - Simplified procedure of hybrid seed production
  - Multiple and diverse germplasm available as parents
    - Any line could be bred as female
    - 97% (2-line) vs 5% (3-line) of germplasm as male
  - Increased chance of developing desirable & heterotic hybrids
  - Multiple cytoplasm courses as female parents

- **Disadvantages**
  - Environmental effect on sterility could cause seed purity problem
Two-line hybrid production in China

Two Line Hybrid Rice In China

Year

Yield (kg/ha)

Area (1000 ha)


2-line Hybrid Yield  All Hybrid Yield  Area

0 200 400 600 800 1000 1200 1400 1600

0 200 400 600 800 1000 1200 1400 1600

6200 6400 6600 6800 7000 7200 7400 7600 7800

2-line Hybrid Yield  All Hybrid Yield  Area
## Hybrid Rice Seed Standard

### Hybrid Rice Seed Standard (GB4404.1 - 1996, China)

<table>
<thead>
<tr>
<th>Seed</th>
<th>Class</th>
<th>Purity (&gt; %)</th>
<th>Cleanliness (&gt; %)</th>
<th>Germination (&gt; %)</th>
<th>Moisture (&lt; %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sterile Line</td>
<td>Core</td>
<td>99.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maiantaier</td>
<td>Foundation</td>
<td>99.0</td>
<td>98.0</td>
<td>85.0</td>
<td>13.0 (indica)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Restore</td>
<td>1st</td>
<td>98.0</td>
<td></td>
<td>80.0</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>96.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mission of IRRI Hybrid Rice Program

- Developing germplasm, parents and hybrids as internationally public goods
- Research new technology for breeding and seed production
- Collaboration with NARS and private sectors in hybrid rice research and production
- Promotion of exchange of information, technology, scientist and germplasm
Strategy of IRRI Hybrid Rice Program

- Focusing on conventional tools and integrate them with proven non-conventional methods to develop the technology

- Developing parental lines, especially female parents with high outcrossing and high quality, to promote hybrid rice spreading

- Facilitating development of close partnership between public and private sectors in national programs

- Intensifying agronomic research to get maximized manifestation of heterosis in hybrids
## Release of IRRI Hybrids in Different Countries (1994-2005)

<table>
<thead>
<tr>
<th>IRRI Hybrid</th>
<th>Released as</th>
<th>Country</th>
<th>Year released</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR64610H</td>
<td>MGR-1</td>
<td>India</td>
<td>1994</td>
</tr>
<tr>
<td>IR64611H</td>
<td>KRH-1</td>
<td>India</td>
<td>1994</td>
</tr>
<tr>
<td>IR64616H</td>
<td>Magat</td>
<td>Philippines</td>
<td>1994</td>
</tr>
<tr>
<td>IR65489H</td>
<td>DRRH-1</td>
<td>India</td>
<td>1996</td>
</tr>
<tr>
<td>IR68284H</td>
<td>Mestizo 1</td>
<td>Philippines</td>
<td>1997</td>
</tr>
<tr>
<td>IR69690H</td>
<td>Sahyadri</td>
<td>India</td>
<td>1998</td>
</tr>
<tr>
<td>IR69690H</td>
<td>HYT-57</td>
<td>Vietnam</td>
<td>1999</td>
</tr>
<tr>
<td>IR69690H</td>
<td>BRRI Dhan Hybrid 1</td>
<td>Bangladesh</td>
<td>2001</td>
</tr>
<tr>
<td>IR69690H</td>
<td>Rokan</td>
<td>Indonesia</td>
<td>2002</td>
</tr>
<tr>
<td>IR75207H</td>
<td>Mestizo 2</td>
<td>Philippines</td>
<td>2002</td>
</tr>
<tr>
<td>IR75217H</td>
<td>Mestizo 3</td>
<td>Philippines</td>
<td>2002</td>
</tr>
<tr>
<td>IR78386H</td>
<td>Mestizo 7</td>
<td>Philippines</td>
<td>2005</td>
</tr>
</tbody>
</table>
# Release of Hybrids by using IRRI Germplasm in Different Countries (1994-2004)

## Hybrids released by NARS using IRRI-bred CMS lines

<table>
<thead>
<tr>
<th>Hybrid name</th>
<th>Country</th>
<th>Year released</th>
</tr>
</thead>
<tbody>
<tr>
<td>APHR-1</td>
<td>India</td>
<td>1994</td>
</tr>
<tr>
<td>APHR-2</td>
<td>India</td>
<td>1994</td>
</tr>
<tr>
<td>CNRH-3</td>
<td>India</td>
<td>1995</td>
</tr>
<tr>
<td>KRH-2</td>
<td>India</td>
<td>1996</td>
</tr>
<tr>
<td>Pant Sankar Dhan-1</td>
<td>India</td>
<td>1997</td>
</tr>
<tr>
<td>ADTRH-1</td>
<td>India</td>
<td>1998</td>
</tr>
<tr>
<td>CORH-2</td>
<td>India</td>
<td>1998</td>
</tr>
<tr>
<td>Narendra Sankar Dhan-2</td>
<td>India</td>
<td>1998</td>
</tr>
<tr>
<td>Rokan</td>
<td>Indonesia</td>
<td>2002</td>
</tr>
<tr>
<td>Maro</td>
<td>Indonesia</td>
<td>2002</td>
</tr>
<tr>
<td>Hipa 3</td>
<td>Indonesia</td>
<td>2004</td>
</tr>
<tr>
<td>Hipa 4</td>
<td>Indonesia</td>
<td>2004</td>
</tr>
</tbody>
</table>

## Hybrids derived from IRRI-bred parental lines and commercialized by private sector

<table>
<thead>
<tr>
<th>Hybrid name</th>
<th>Country</th>
<th>Year released</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biganti</td>
<td>Philippines</td>
<td>2004</td>
</tr>
<tr>
<td>Intani 1</td>
<td>Indonesia</td>
<td>2001</td>
</tr>
<tr>
<td>Intani 2</td>
<td>Indonesia</td>
<td>2001</td>
</tr>
<tr>
<td>PHB-71</td>
<td>India</td>
<td>1997</td>
</tr>
<tr>
<td>Proagro 6201</td>
<td>India</td>
<td>2000</td>
</tr>
<tr>
<td>HR 120 (6444)</td>
<td>India</td>
<td>2001</td>
</tr>
</tbody>
</table>
## Germplasm Shared

<table>
<thead>
<tr>
<th>Country</th>
<th>CMS</th>
<th>Maintainer</th>
<th>Restore</th>
<th>TGMS</th>
<th>Hybrid</th>
<th>Population</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Australia</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>8</td>
<td>8</td>
<td>11</td>
<td>193</td>
<td>20</td>
<td>53</td>
<td>8</td>
</tr>
<tr>
<td>China</td>
<td>17</td>
<td>17</td>
<td>7</td>
<td>9</td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>India</td>
<td>85</td>
<td>85</td>
<td></td>
<td>20</td>
<td>53</td>
<td></td>
<td>444</td>
</tr>
<tr>
<td>Indonesia</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td>23</td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>Iran</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
<td>14</td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>Japan</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Kenya</td>
<td>11</td>
<td>11</td>
<td>49</td>
<td>2</td>
<td></td>
<td></td>
<td>73</td>
</tr>
<tr>
<td>Malaysia</td>
<td>5</td>
<td>5</td>
<td></td>
<td>10</td>
<td>4</td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>Myanmar</td>
<td>4</td>
<td>4</td>
<td></td>
<td>18</td>
<td>17</td>
<td></td>
<td>43</td>
</tr>
<tr>
<td>Nepal</td>
<td>12</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>Pakistan</td>
<td>8</td>
<td>8</td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>Philippines</td>
<td>40</td>
<td>37</td>
<td>55</td>
<td>4</td>
<td>121</td>
<td></td>
<td>257</td>
</tr>
<tr>
<td>Russia</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>36</td>
</tr>
<tr>
<td>Thailand</td>
<td>14</td>
<td>14</td>
<td>12</td>
<td>10</td>
<td>13</td>
<td></td>
<td>63</td>
</tr>
<tr>
<td>USA</td>
<td>8</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Vietnam</td>
<td>10</td>
<td>10</td>
<td></td>
<td>5</td>
<td>6</td>
<td></td>
<td>31</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>260</td>
<td>257</td>
<td>369</td>
<td>50</td>
<td>331</td>
<td></td>
<td>1275</td>
</tr>
</tbody>
</table>
## Progress of "Super High-Yielding" Hybrid Rice Program in China

<table>
<thead>
<tr>
<th>Stage</th>
<th>Goal (single-season)</th>
<th>Progress (2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield (t/ha)</td>
<td>Breeding</td>
</tr>
<tr>
<td></td>
<td>Years</td>
<td>Commercialization</td>
</tr>
<tr>
<td>Start</td>
<td>8.25</td>
<td>1997</td>
</tr>
<tr>
<td>Phase I</td>
<td>10.5</td>
<td>Finished</td>
</tr>
<tr>
<td></td>
<td>1996 - 2000</td>
<td>Large area extension</td>
</tr>
<tr>
<td>Phase II</td>
<td>12.0</td>
<td>Finished</td>
</tr>
<tr>
<td></td>
<td>2000 - 2005</td>
<td>Started</td>
</tr>
<tr>
<td>Phase III</td>
<td>13.5</td>
<td>Started</td>
</tr>
<tr>
<td></td>
<td>2005 - 2010</td>
<td></td>
</tr>
</tbody>
</table>
Morphological Model of Super High-yielding Hybrid Rice

- Plant height = 100 cm, with culm length = 70 cm
- Uppermost three leaves:
  - Flag leaf, long, 50 cm, higher than the panicle top 20 cm. The 2\textsuperscript{nd} leaf from the top: 10\% longer than the flag leaf, and over the top of the panicle. The 3\textsuperscript{rd} leaf = the middle position of the panicle
  - Erect: the leaf angles of the flag, 2\textsuperscript{nd} and 3\textsuperscript{rd} leaves are around 5, 10, 20 degrees, till mature
  - Narrow, V-shape and thick: narrow with 2 cm when flattened.
- Plant type: moderate compact with moderate tillering capacity; drooping panicles after filled, above ground ~ 60 cm, erect-leaved canopy without appearance of the panicles
- Panicle weight and number: grain weight per panicle = 5 g, 2.7 million panicles per hectare.
- Leaf area index (LAI) and ratio of leaf area to grains: the LAI is ~ 6.5 based on the uppermost three leaves, the ratio of leaf area to grain weight is 100 : 2.2-2.3, meaning that to produce 2.2-2.3 grams of rice, 100 cm\textsuperscript{2} of the upper three functional leaves are needed.
- Harvest index > 0.55
Hybrid Heterosis in Rice

Indica x japonica
Indica x javanica
japonica x javanica
indica x indica
japonica x japonica
Inter-subspecific hybrid rice breeding

- Difficult in breeding inter-subspecific hybrid rice
  - Low seed set
  - Tall plant height
  - Poor grain-filling
  - Late maturity
  - Grain quality market

- Solution for breeding of inter-subspecific hybrid rice
  - wide compatibility (WC) genes
  - allelic dwarf gene
  - indica/javanica hybrids in indica rice growing region
  - japonica/javanica hybrids in japonica rice growing region
### Future Opportunity: Enhance yield heterosis

- Exploiting subspecies heterosis
- Applying biotechnology for parent selection (heterotic groups and/or heterotic gene blocks)

<table>
<thead>
<tr>
<th>Hybrid</th>
<th># of heterotic hybrids</th>
<th>Total # of hybrids</th>
<th>% of heterotic hybrids</th>
<th>Yield advantage (%) over best inbred check</th>
</tr>
</thead>
<tbody>
<tr>
<td>indica / indica</td>
<td>34</td>
<td>85</td>
<td>40</td>
<td>1-80</td>
</tr>
<tr>
<td>Indica / NPT</td>
<td>20</td>
<td>40</td>
<td>50</td>
<td>6-131</td>
</tr>
</tbody>
</table>
### Performance of hybrid seed production in tropical countries (2003-2004)

<table>
<thead>
<tr>
<th>Country</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>India</td>
<td>1,600</td>
</tr>
<tr>
<td>Vietnam</td>
<td>2,000</td>
</tr>
<tr>
<td>Philippines</td>
<td>810 (04DS)</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>800</td>
</tr>
<tr>
<td>Indonesia</td>
<td>500</td>
</tr>
<tr>
<td>China</td>
<td>2,750</td>
</tr>
</tbody>
</table>

Future Opportunity:
Increase yield of hybrid seed production

- Developing high outcrossing parents
- Improving seed production technology
- Training seed growers
- Selecting adequate location / season
Hybrid Rice Seed Production

In Asia

In United States
Future Opportunity:
Improve hybrid rice grain quality

Measurements of Rice Grain Quality:
- Milling yield
  - Total milling yield
  - Whole milling yield
- Chalk
- Amylose content
- Gel Temperature (ASV)
- Length, width, L/W
- Protein
- Aroma
Future Opportunity:
Improve hybrid rice grain quality

<table>
<thead>
<tr>
<th>Trait</th>
<th>Inbred</th>
<th>Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Milling (%)</td>
<td>69.1</td>
<td>68.2</td>
</tr>
<tr>
<td>Whole Milling (%)</td>
<td>48.7</td>
<td>45.4</td>
</tr>
<tr>
<td>Chalk (%)</td>
<td>13.5</td>
<td>20.6</td>
</tr>
<tr>
<td>Amylose (%)</td>
<td>19.8</td>
<td>20.6</td>
</tr>
<tr>
<td>GT</td>
<td>4.3</td>
<td>5.5</td>
</tr>
<tr>
<td>Length</td>
<td>6.9</td>
<td>7.1</td>
</tr>
<tr>
<td>L/W</td>
<td>3.2</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Data from National Cooperative Testing (NCT), Philippines, 2004-2005
Difference of Whole Milling Yield and Chalk between Inbreds and Hybrids

Average Whole Milling (%)
Hybrid = 45.4
Inbred = 48.7

Average Chalk (%)
Hybrid = 20.6
Inbred = 13.5
Difference of Whole Milling Yield and Chalk between Inbreds and Hybrids

Data source: 2004 and 2005 NCT, Philippines
Future Opportunity: Develop hybrids for unfavorable environments

Hybrids Have Substantially Improved Yield under Severe Lowland Stress (ca. 1 t/ha). (IRRI, G. Atlin, 2005)
Future Opportunity:
Improve agronomic management and deployment strategy

ShanYou 63 grown under different nitrogen management (S. Peng, IRRI)